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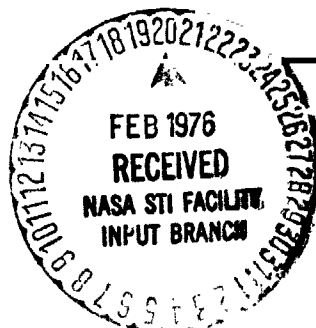
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TWIN CITIES MINING RESEARCH CENTER



**U.S. Department of the Interior
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**Experimental System for Drilling Simulated
Lunar Rock in Ultrahigh Vacuum**

by

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EXPERIMENTAL SYSTEM FOR DRILLING SIMULATED
LUNAR ROCK IN ULTRAHIGH VACUUM

by

Wallace W. Roepke¹

ABSTRACT

The experimental apparatus designed for studying drillability of hard volcanic rock in a simulated lunar vacuum of 5×10^{-10} torr is described. The engineering techniques used to provide suitable drilling torque inside the ultrahigh vacuum chamber while excluding all hydrocarbon are presented in detail. Totally unlubricated bearings and gears were used to better approximate the true lunar surface conditions within the ultrahigh vacuum system. The drilling system has a starting torque of 30 in-lb with an unloaded running torque of 4 in-lb. Nominal torque increase during drilling is 4.5 in-lb or a total drilling torque of 8.5 in-lb with a 100-lb load on the drill bit at 210 rpm. This research has shown conclusively that it is possible to design operational equipment for moderate loads operating under UHV conditions without the use of sealed bearings or any need of lubricants whatsoever.

The work makes a significant contribution to the testing of experimental apparatus in severe vacuum environments. It has also proven that operating mechanisms may be designed which will not degrade mirrors or invalidate results due to nearby outgassing of lubricated parts during operation in the hard vacuum environment of space.

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INTRODUCTION

The U.S. Bureau of Mines has been studying the problems associated with the handling of lunar surface materials for several years under the sponsorship of NASA's Office of Advanced Research and Technology².

²This work has been performed under NASA contract No. R-09-040-001 monitored by Mr. James Gangler from the Office of Advanced Research and Technology.

Hundreds of millions of years exposure to hard vacuum, radiation and particle bombardment from space have produced a lunar moon surface that appears totally outgassed to a considerable depth. This presents rock surfaces for materials handling which must be considered totally free of any lubricant; hydrocarbon, water vapor, or gaseous. Basic information is needed on friction, drilling, breaking, and handling such materials in the lunar environment.

Studies in these various areas have been carried on as a series of related research projects at several different Bureau Research Centers (1).³ The experimental apparatus described in this paper has been designed to study the drilling behavior of volcanic rock (simulated lunar material) in ultrahigh vacuum (simulated lunar pressure).

The drill parameters being used in this project are restricted to those which are considered practical for actual manual use on the moon.

Extensive preliminary work has been done by others on the flute design and diamond setting (2) for augering fragmented material from the dry holes and the effects on the drill bits of dry drilling (3, 4) in atmospheric pressure and humidity.

³Underlined numbers in parentheses refer to items in the list of references at the end of this report.

Laboratory conditions and sample preparation techniques have also been presented previously (5). This paper will be limited to a presentation of design and operational capability of the experimental drilling apparatus for ultrahigh vacuum use.

General Description

The total experimental drilling system has two major components; the ultrahigh vacuum (UHV) chamber with associated instrumentation and, the drilling assembly with associated recording equipment (Fig. 1).

The UHV system (described elsewhere (5)), is a standard commercial unit capable of achieving a pressure of better than 5×10^{-12} clean, dry, and empty. Normal test procedures used for this project dictated a pressure region from 5×10^{-9} to 5×10^{-11} torr. Instrumentation for this system includes both a nude Bayard-Alpert gauge and a quadrupole mass spectrometer for residual gas analysis.

The drilling apparatus (Fig. 2), is an experimental design to simulate the drilling of materials on the lunar surface in the lunar vacuum. This precludes the use at any hydrocarbon lubricant or gaseous environment. The drill apparatus is composed of four integrated sections.

The first of these, the drill support frame, is mounted within the lower vacuum chamber section. This is rapidly locked in place with clamping devices designed specifically to allow precise alignment of the other sections (11). All of the other sections are mounted on or connected to this supporting frame.

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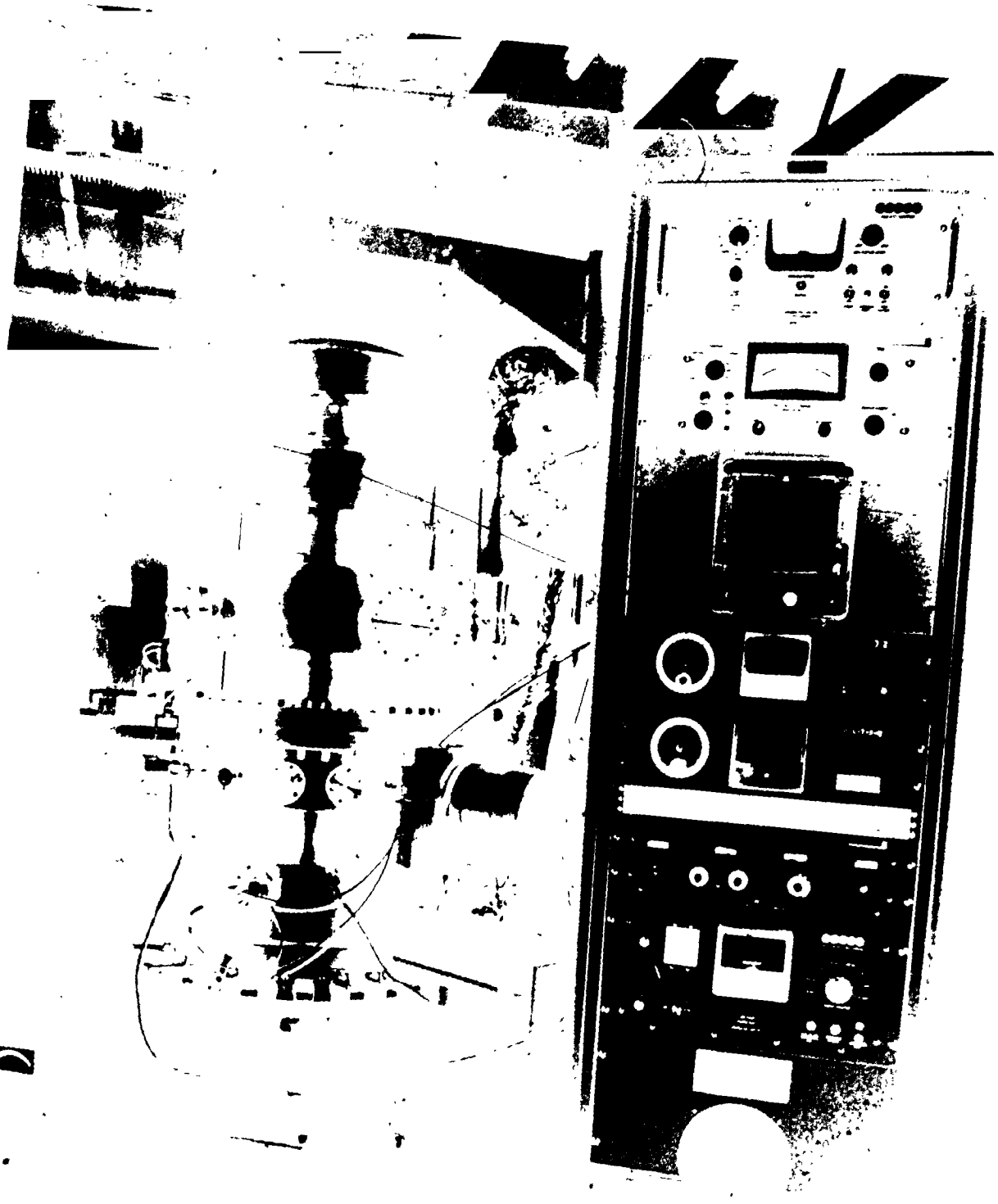


FIGURE I.- UHV Drilling System

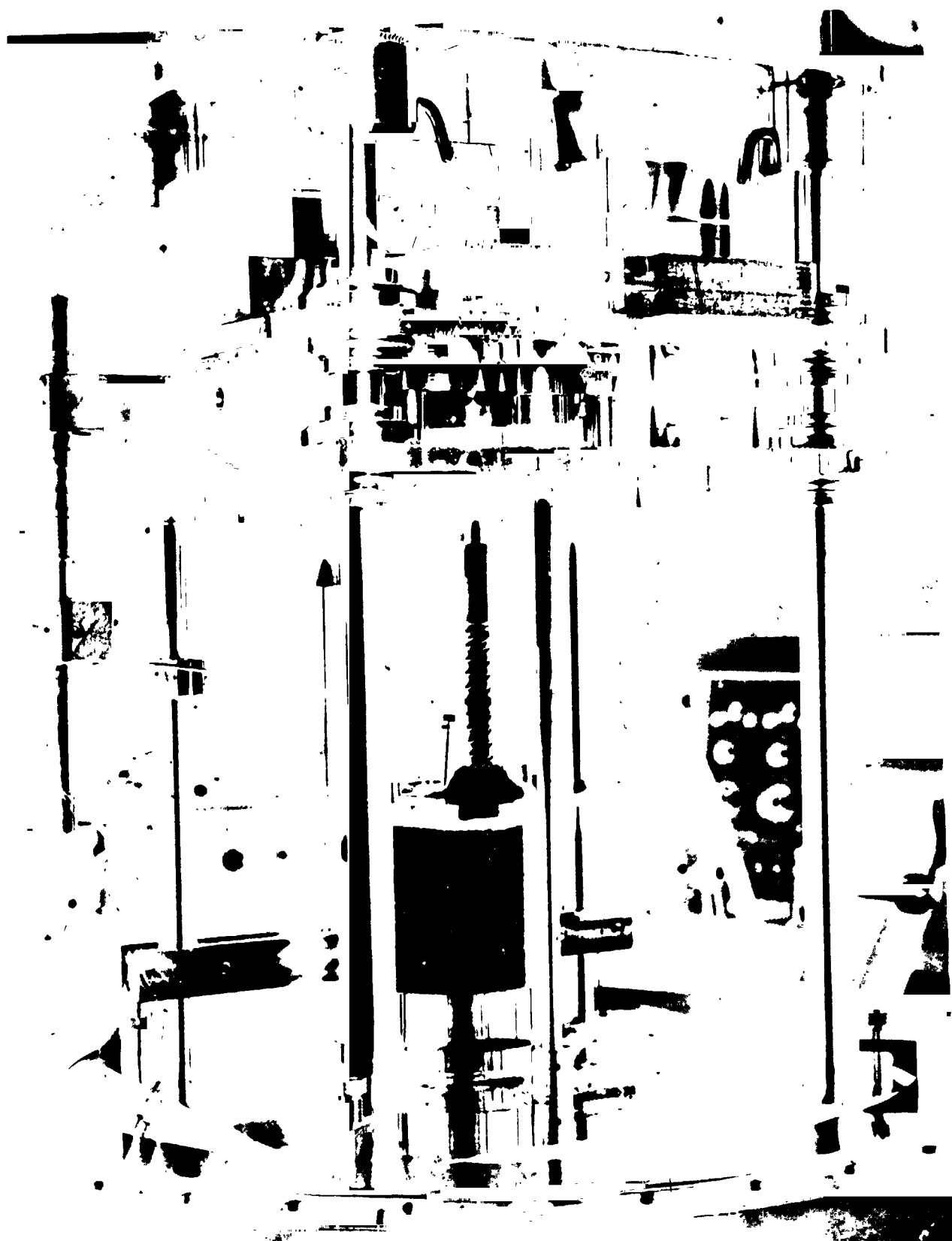


FIGURE 2.-UHV Drilling Rig With Test Sample in Place

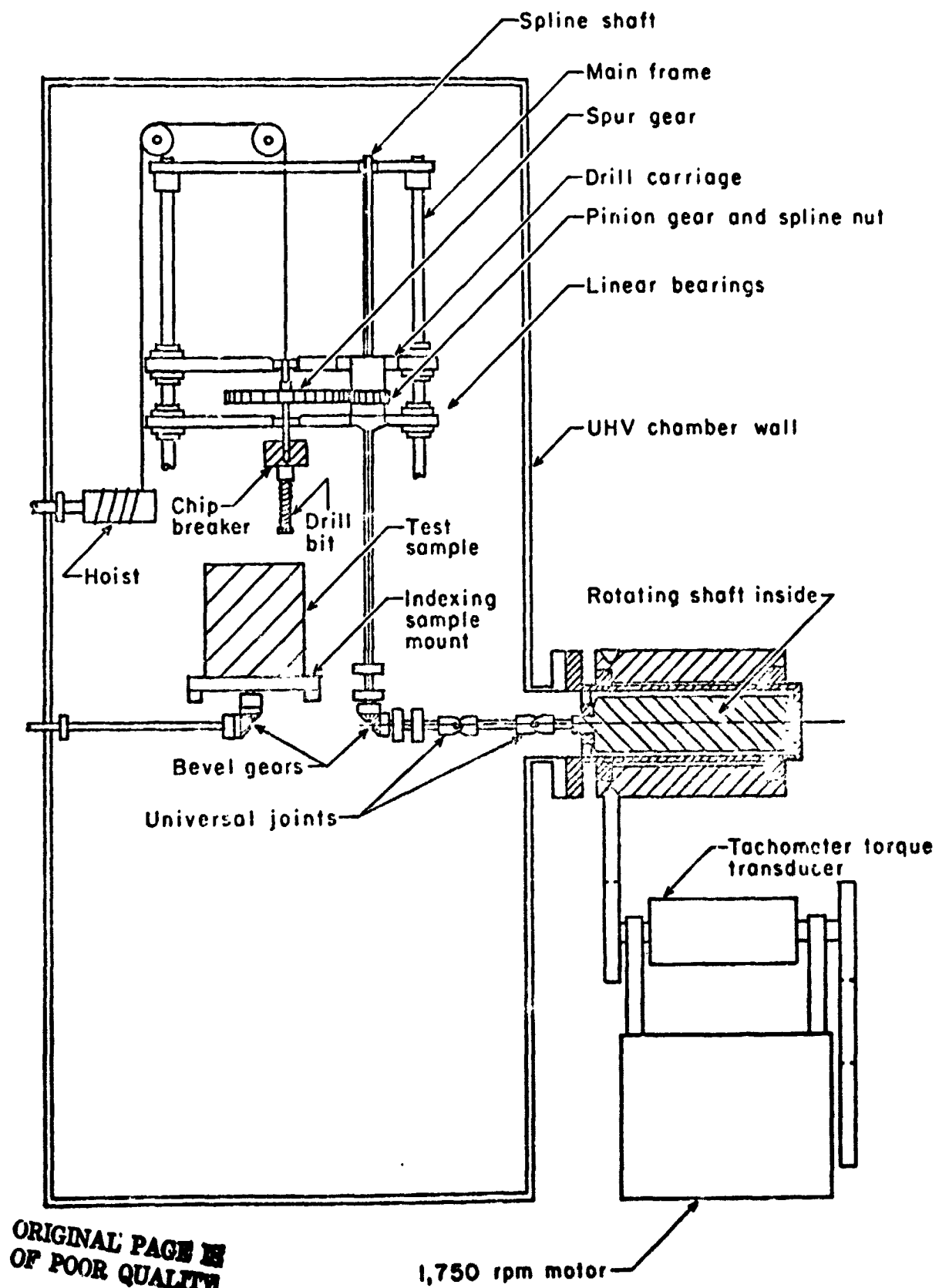
The second section of the drill apparatus is the drill carriage and hoist mechanisms. The drill carriage positions the drill at the vertical center line of the support frame. Attached on the center line of the carriage is a hoist cable which is run over pulleys mounted in the top plate of the support frame and down to a drum on a rotary feed through. The rotary feed through, mounted in the wall of the vacuum chamber, provides vertical motion to the drill carriage and yet maintains UHV. The drill carriage alone weighs 42 pounds but the top plate has space available for an additional 150 lbs of dead weights. Total vertical stroke for the drill at 42 lbs is 7 inches but with the dead weight added this is reduced to a maximum of 3 inches.

Since the load on the cable take-up drum could be high a straight through shaft type rotary feed through, has been used. The only type which met the requirements of this system was available from the Ferrofluidic Corp. of Burlington, Mass.⁴ This feedthrough seals the

⁴Reference to specific brand names is made for identification only and does not imply endorsement by the Bureau of Mines.

straight through rotary shaft magnetically by means of colloidal suspension of ferrous material in a low vapor pressure carrier, in this case Monsanto, Santovac 5, diffusion pump oil. To preclude the possibility of creep or vapor phase during UHV bakeout the rotary feedthrough is wrapped with a copper coil for continuous water cooling.

The third section of the apparatus is the drill string. This includes the external power source and rotary magnetic coupling needed to drive the drill string from outside the UHV (Fig. 3). This section of the total system was the most critical to design if a valid lunar simulation were to be maintained.



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FIGURE 3.— Schematic Drawing of Ultrahigh Vacuum Drilling Apparatus with Sample Showing Power Train

The drill string consists of: miter gear set, spline nut on a spline shaft, spur and pinion gear, drill bit, and eleven radial bearings. The miter gear set permits a 90° change from the horizontal rotary input to the vertical spline shaft. The spline nut provides vertical motion up or down this spline shaft and also provides rotary motion to the spur gear by being mounted in the pinion gear. Thus the entire drill carriage has vertical mobility while maintaining rotary input to the drill bit.

The design makes available a hydrocarbon free environment by using bearings and gears which require no lubricant. Although several techniques were tried, the only bearings and gears found fully satisfactory were made using a proprietary impregnated polyimide (PI) formulation supplied under the trade name of Feuralon-type AW by the Bomol Co. of Newton, Mass. The bearing races and balls are stainless steel but the retainers are made with the silver and tungsten disulfide impregnated PI.

In addition to the bearing retainers all steel pins in the universal joints and one gear in each pair has been changed to PI material. To prevent using a large amount of PI on the spur gear, teeth were cut in a ring of PI placed on a stainless steel hub. Thus, all moving parts directly in the drill string are dry lubricated by the filled PI. This technique has eliminated short term failure of bearings and gears running dry in an ultrahigh vacuum.

The polyimide is made by a reaction of pyromellitic dianhydride and an aromatic diamine to form polyimide acid which is then heated to remove water thus forming the polypyromellitimide plastic. The Ag and WS₂ increase the natural lubricity of the material (3, 4). This

material should not be confused with the nylon polyamides or polytetrafluoroethylene (PTFE) since none of these materials would have the UHV characteristics of PI (7, 8, 9, 10).

Since several weeks to several months, depending on test material, are spent on system and sample evacuation to the 5×10^{-10} torr region it was not considered practical to drill only one hole at a time. Therefore the fourth section of this experimental apparatus provides rotary sample indexing. The test sample is clamped rigidly to an offcenter rotary table which may be positioned and locked from outside the UHV chamber. The offcenter rotary table allows several holes to be drilled in the periphery of the test sample for every evacuation of the UHV chamber.

Test Procedures

The test sample undergoes preliminary preparation as described elsewhere (5). Once the sample is mounted in the rotary index holder it is collared to a depth of 1/8-in at 5 points using an old drill bit. The drill to be used for the UHV testing is then mounted and the system is closed and handled like any other UHV chamber being evacuated.

After the desired pressure region has been achieved drilling can commence. Normal test parameters being recorded are; penetration, torque and rpm. Load is checked by keeping a slack hoist cable on the drill carriage. Drill speed during testing is 210 rpm using a 100 lb. dead weight load. The penetration rate is dependent upon rock type and drill design being used.

After the desired depth is reached in any test the drill is hoisted clear of the hole and the sample indexed to the next position.

Before, during, and after each test total pressure and partial pressure of residual gasses in the UHV chamber are being recorded.

Preliminary Results

Total time on the unlubricated bearings in the drill string is approximately 12-1/2 hours. About 1/2 of this time was spent running in the bearings in air with the remaining time in vacuum. Mass spectrometer studies of the residual gas background during pumpdown and operation of the apparatus in UHV indicates that the PI material in bearings and gears does not contribute to this background. Even when the drill is operated with a bakeout temperature of 170° C on the chamber to accelerate the degassing and cleanup the only additional background seen is sorbed gasses being driven off the moving parts. This gives a 1/2 to 3/4 decade pressure rise but this would be expected for any system. Nothing significant, i.e., no trace amount is seen past 44 atomic mass units (44 amu = CO₂).

Starting torque of the drill is 30 in-lb with an unloaded running torque of 4 in-lb. Nominal torque increase during drilling at 210 rpm with a 100 lb bit load is 4.5 in-lb. Thus total running torque during full load for a test will be approximately 8.5 in-lb. This is expected to vary slightly with various test and drill bit factors, i.e., drill shape, drill age, number of face diamonds, rock type, etc. There has been no discernable difference in torque for an unloaded drill between or between ambient and 170° C in UHV.

CONCLUSIONS

This project has shown conclusively that it is possible to design operational equipment for moderate loads operating under ultrahigh vacuum conditions without the use of sealed bearings or the need for any lubricants whatsoever. This work is significant not only for the testing potential of the experimental apparatus, but because it has proven that operating mechanisms may be designed which will not degrade mirrors or invalidate other instrument results due to nearby outgassing of lubricated parts during operation in the hard vacuum environment of space. This should prove significant for both of the space probes and the approaching skylab series of tests.

ACKNOWLEDGMENTS

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